POWER LINE INTERFERENCE REMOVAL FROM ELECTROCARDIOGRAM USING A SIMPLIFIED LATTICE BASED ADAPTIVE IIR NOTCH FILTER

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Abstract-**In this paper we propose the use of a lattice based second order infinite impulse response (IIR) notch filter with a simplified adaptation algorithm for removal of power line frequency from ECG signals. The performance of this filter is better as compared to a second order infinite impulse response (IIR) notch filter for a real time ECG recording systems where the frequency of line varies over a narrow range about 50 Hz.**
Keywords: **lattice structure,3-dB bandwidth, mean square error**

I. INTRODUCTION

A major problem in the recording of electrocardiogram (ECG's) is that the measured signal is corrupted by 50 Hz power line interference [1]. The traditional approach for this interference removal is to use a digital notch filter characterized by a unit gain at all frequencies except at notch frequency where the gain is almost zero. A number of FIR and IIR filters have been proposed for this purpose [3]. But for a real time ECG recording the power line frequency varies over a narrow range of frequencies about the base frequency of 50 Hz. The specifications for example are 50 Hz $\pm$ 3 %. In the traditional approach IIR notch filter with a narrow 3-dB rejection bandwidth is preferred to faithfully separate the sinusoidal and broadband components. But the response of such a filter is not suitable when frequency has changed, so an adaptive notch filter is required for this purpose. It is so far known that IIR adaptive notch filter realization performs better than finite impulse response (FIR) counterparts as regards the number of coefficients and computational complexity. In implementation of IIR adaptive notch filters, a number of structures and adaptation algorithms have been proposed.

Most of the proposed algorithms are based on gradient descent methods that require at least two filter structures, one of them for generation of gradient signals used in adaptation algorithms. This adds to hardware complexity. Further, since the gradient filter also needs to be tuned during adaptation, it adds to computation complexity also.

In this paper we use a second–order IIR adaptive notch filter that uses a simple adaptation algorithm that does not require a gradient signal-generating filter [2]. Instead the adaptation signal is generated by the same structure as one of its internal states. This structure therefore reduces both hardware and computation complexities as compared to gradient descent based algorithms. Lattice structure realization is used as it has several advantages over direct form structures [5]. For example a lattice structure realization requires a minimum number of multipliers and allows independent tuning of the notch frequency and attenuation bandwidth**.**

II. SECOND ORDER ADAPTIVE NOTCH FILTER

The adaptive filter in consideration is characterized by a second order transfer function H (z) [2]

$$H(z) = \frac{1+\alpha}{2}\,\frac{1-2\beta(k)z^{-1}+z^{-2}}{1-\beta(k)(1+\alpha)z^{-1}+z^{-2}} \qquad (1)$$

The coefficients $\beta(k)$ and α are related to the notch frequency w_0 and 3-dB attenuation bandwidth Ω by

$$\beta(k) = \cos(w_0)$$
$$\alpha = \frac{1-\tan(\Omega/2)}{1+\tan(\Omega/2)} \qquad (2)$$

In tracking the sinusoid of unknown frequency w_s, a simplified adaptation algorithm is used and is given by

$$\beta(k+1) = \beta(k) + \mu\, y(k)\, x(k) \qquad (3)$$

where μ is the stepsize adaptation constant, y(k) is the output of the notch filter and x(k) is an adaptation signal.

A number of different structures can be used to implement Eq. (1) but due to the advantages of lattice structure over other structures a lattice structure is used. Fig (1) shows a lattice structure realization of the adaptive notch filter H (z).

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Abstract

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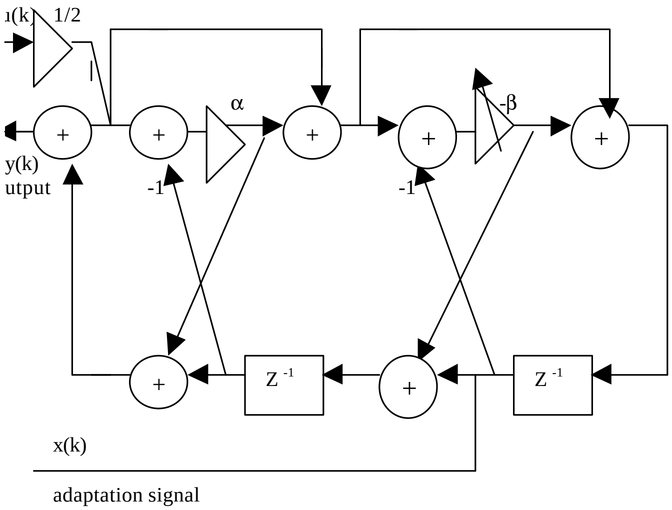

Fig.1 Lattice Structure realization

The adaptation signal x (k) is generated by the same filter structure. The transfer function from the input u (k) to x (k), F (z) is

$$F(z) = \frac{(1+\alpha)(1-\beta(k))}{2} \frac{z^{-1}}{1-\beta(k)(1+\alpha)z^{-1}+\alpha z^{-2}} \quad (4)$$

III. NOTCH FILTERING

Given the input ECG signal u (k), the sampling frequency f_s Hz, sinusoidal frequency f_d Hz and notch bandwidth BW Hz, the design proceeds as follows

(i) Calculate $w_0 = 2\pi(f_d/f_s)$, $\Omega = 2\pi(BW/f_s)$

(ii) Using Eq. (2), calculate the filter coefficients α and $\beta(0)$.

(iii) Choose arbitrary initial conditions y(-1) and y(-2), the output is calculated using Eq. (1)

$$y(k) = y(k-1)\beta(k)(1+\alpha) - \alpha\, y(k-2) + \frac{1+\alpha}{2}[u(k) - 2\beta(k)\, u(k-1) + u(k-2)]$$

(iv) The coefficient $\beta(k)$ is updated by using the relation

$$\beta(k+1) = \beta(k) + \mu\, y(k)\, x(k)$$

(v) The adaptation signal x (k) is obtained using Eq. (4)

$$x(k) = \beta(k)(1+\alpha)\, x(k-1) - \alpha\, x(k-2) + \frac{(1+\alpha)(1-\beta(k))}{2} u(k-1)$$

For non-adaptive IIR filtering the coefficient $\beta(k)$ is **filter at** d constant and thus steps (iv) and (v) are redundant. To test the above algorithm an ideal ECG signal was added with power line interference where the frequency of the line varied in a narrow range. The various ECG signals tested were:

(1) ECG signal with 48.5 Hz noise added
(2) ECG signal with 49 Hz noise added
(3) ECG signal with 49.5 Hz noise added
(4) ECG signal with 50 Hz noise added
(5) ECG signal with 50.5 Hz noise added
(6) ECG signal with 51 Hz noise added

In order to compare the adaptive filtering process with the non adaptive IIR filtering process, the mean square error defined in eq. (5) was calculated

$$E = \frac{1}{N} \sum_{n=n_0+1}^{n=n_0+N} |y(n) - s(n)|^2 \quad (5)$$

where N is the size of the window and n_0 is the starting time. The value of n_0 was chosen as 400 so that the effect of transients could be neglected.

IV. RESULTS

The outputs of the IIR notch filter, for the ECG signals with power line interference of varying frequency (signals 1-6), without using adaptation algorithm and with adaptation algorithm are shown in figs. 2-7. The IIR notch filter practically fails to eliminate the line interference at frequencies other than 50 Hz, whereas adaptive IIR notch filter gives a nearly noise free output.

The Mean square error calculated by using the Eq. (5) was plotted for different bandwidths for both the second order IIR and the second order adaptive IIR filters.

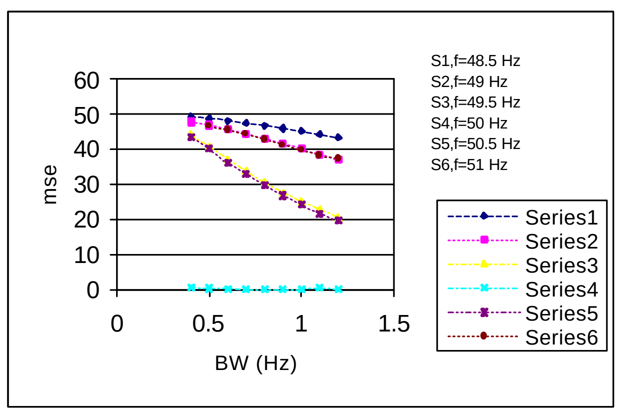

Fig.8. Mean square error vs Bandwidth for a second order IIR notch filter at different frequencies.

In fig. (8) the series 1,2,3,4,5,6 indicate the mse of the notch filter at frequencies 48.5 Hz, 49 Hz, 49.5 Hz, 50 Hz, 50.5 Hz and 51 Hz respectively. From fig. (8) the mse for IIR notch filter is minimum at 50 Hz but becomes significant as the line wanders away from 50 Hz. Even if the bandwidth is increased to1 Hz the error is significant.

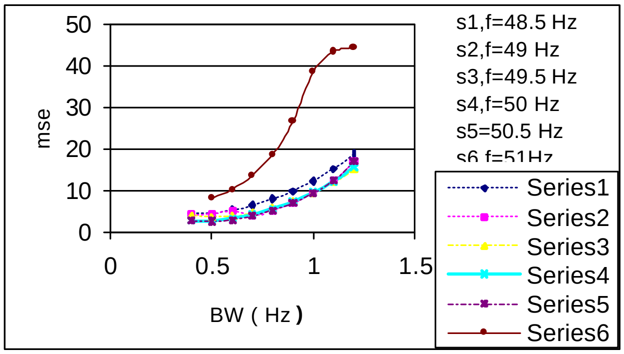

Fig.9 Mean square error vs BW for second order adaptive IIR notch filter at different frequencies

In fig. (9) the series 1,2,3,4,5,6 indicate the mse of the notch filter at frequencies 48.5 Hz, 49 Hz, 49.5 Hz, 50 Hz, 50.5 Hz and 51 Hz respectively. From fig. (9), the mean square error for an adaptive IIR filter is quite small and remains nearly constant even as the line frequency changes from 50 Hz. Only at 51 Hz the mean square error becomes significant as the bandwidth is increased above 1Hz.(uppermost curve).

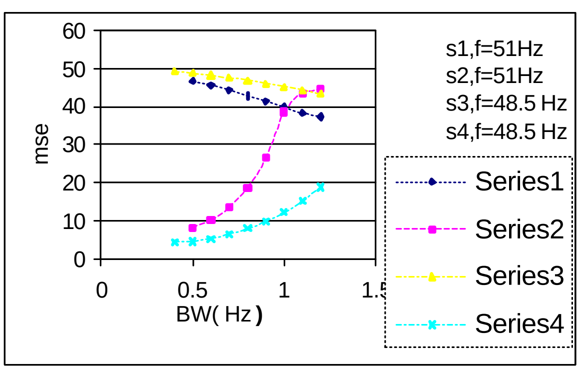

Fig. (10) Comparison of adaptive and non-adaptive IIR notch filters at frequencies of 48.5 Hz and 51 Hz.

In fig. (10), the series s1 and s3 indicate the mean square error for non-adaptive IIR notch filter while series s2 and s4 indicate the mse for adaptive IIR notch filter at frequencies 51 Hz and 48.5 Hz resp. Thus at a frequency of 48.5 Hz and 51 Hz i.e. the upper and lower limits of line frequency variation, the response of an adaptive IIR notch filter is much better as compared to IIR filter used without adaptation. Thus for power line interference removal, though an adaptive filter increases the computational load, it is to be preferred as compared to a non-adaptive filter because it can adjust to small changes in the frequency of line. In addition it can be easily implemented in hardware using a lattice structure.

V. Conclusion

This paper identifies the problem of line interference in real time ECG measuring systems where the frequency of line is not stable. A suitable remedy for the above problem in the form of second order adaptive IIR notch filter is proposed. Experimental results show that this filter gives a better performance as compared to non-adaptive second order IIR notch filter when the frequency of line varies.

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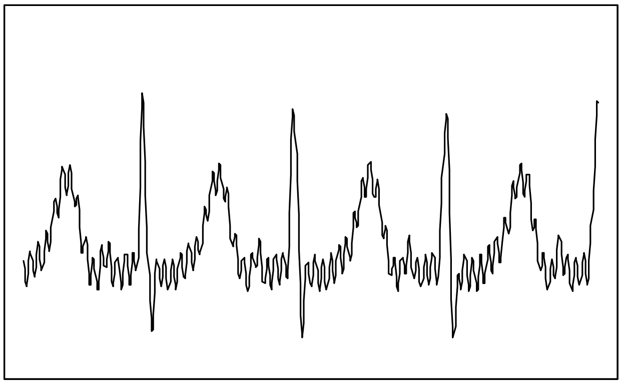
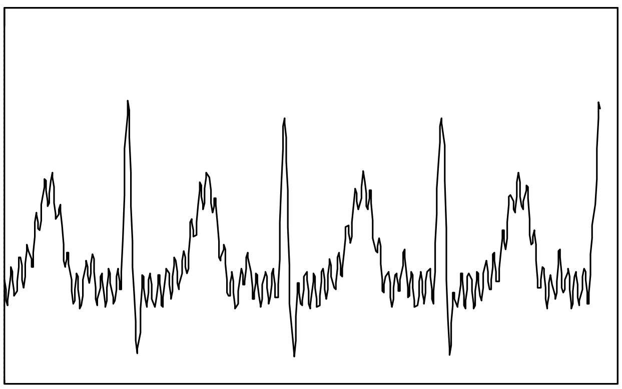
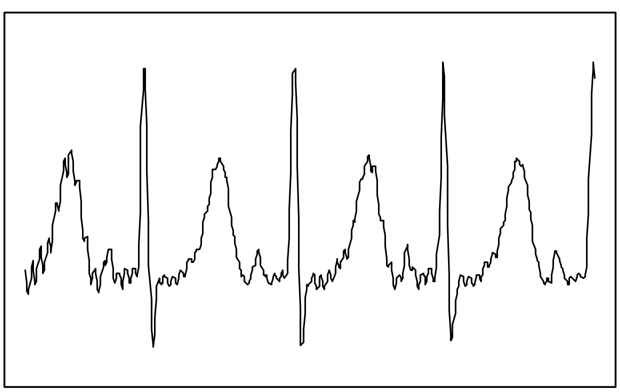


(a) ECG signal with 48.5 Hz Interference

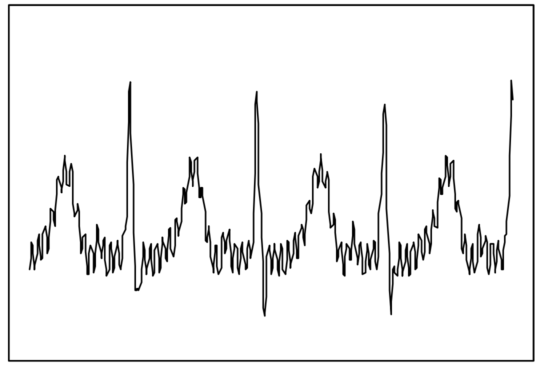


(b) IIR Filtering without adaptation algorithm
y(-1) = 0,y(-2)=0, and BW = 0.5 Hz

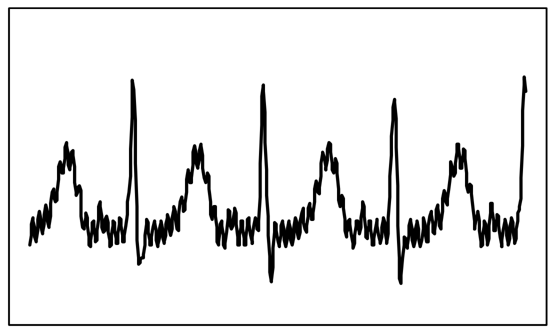


(c) Adaptive IIR Filtering
y(-1) = 0, y(-2) =0, BW =0.5 Hz

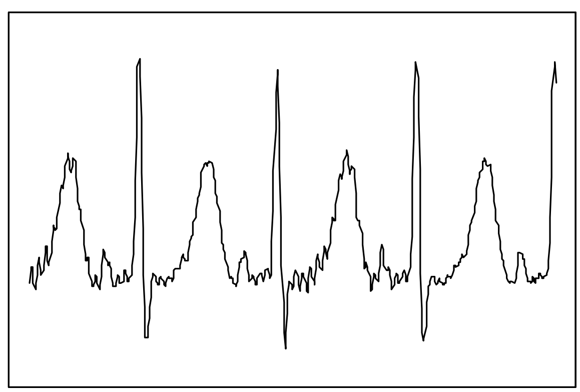
Fig. 2. Comparison of the two IIR notch filters at line frequency = 48.5 Hz. The first 400 samples are neglected and initial conditions are assumed to be zero.
(f_d = 400 , f_s= 50 Hz)



(a) ECG signal with 49 Hz interference

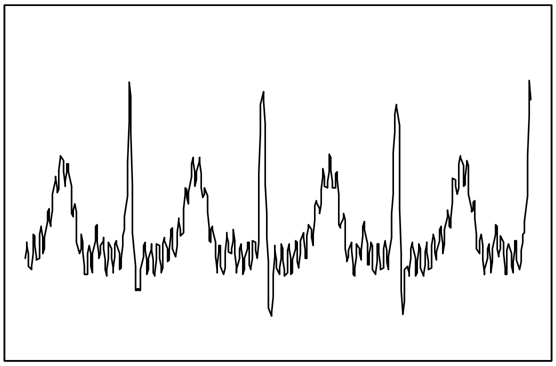


(b) IIR filtering without adaptation algorithm
y(-1) = 0,y(-2) =0, BW = 0.5 Hz

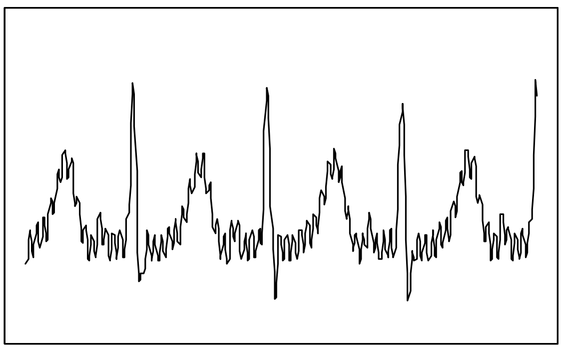


(c) Adaptive IIR Filtering
y(-1) = 0, y(-2) =0, BW =0.5 Hz

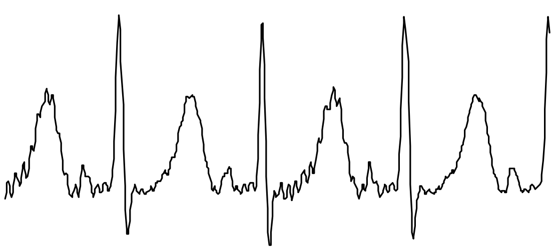
Fig. 3. Comparison of the two IIR notch filters at line frequency = 49 Hz. The first 400 samples are neglected and initial conditions assumed to be zero. (f_d = 400 , f_s= 50 Hz)



(a) ECG signal with 49.5 Hz Interference

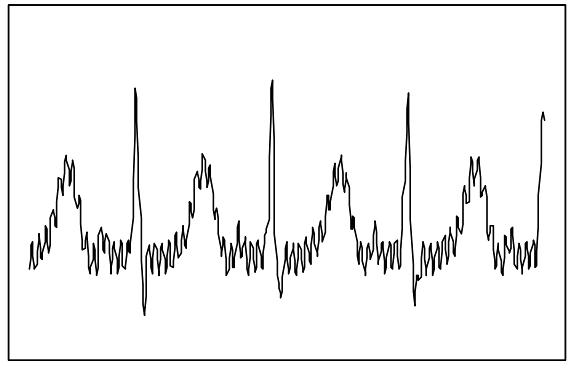


(b) IIR Filtering without adaptation algorithm
y(-1) = 0, y(-2) =0, BW =0.5 Hz



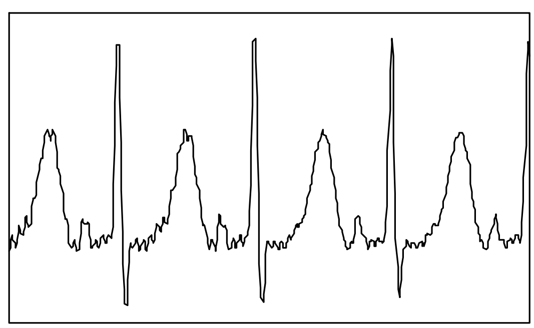
(c) Adaptive IIR Filtering
y(-1) = 0, y(-2) =0, BW =0.5 Hz

Fig. 4. Comparison of the two IIR notch filters at line frequency = 49.5 Hz. The first 400 samples are neglected and initial conditions are assumed to be zero. (f_d = 400 , f_s= 50 Hz).



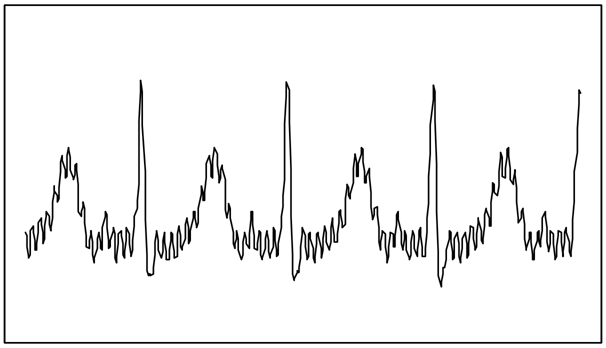
(a) ECG signal with 50 Hz Interference

(b) IIR Filtering without adaptation algorithm
y(-1) = 0, y(-2) =0, BW =0.5 Hz

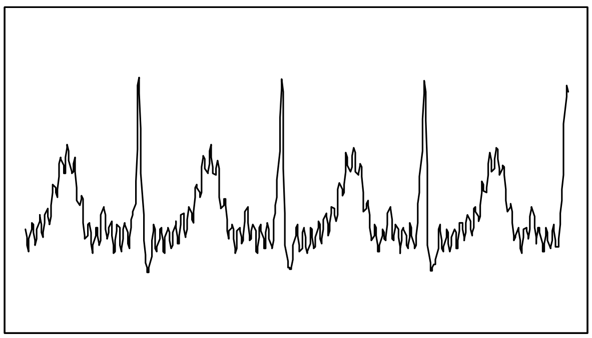


(c) Adaptive IIR Filtering
y(-1) = 0, y(-2) =0, BW =0.5 Hz

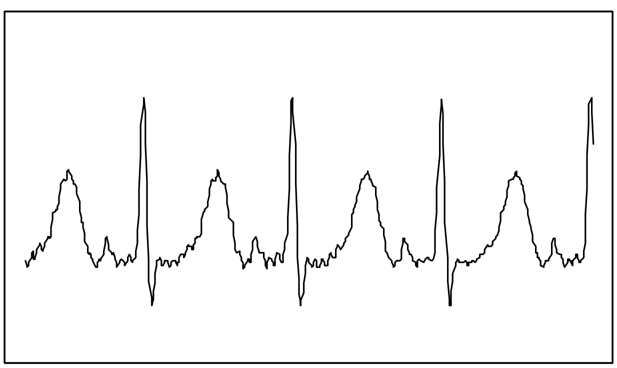
Fig. 5. Comparison of the two IIR notch filters at line frequency = 50 Hz. The first 400 samples are neglected and the initial conditions are assumed to be zero. (f_d = 400 , f_s= 50 Hz)



(a) ECG signal with 50.5 Hz Interference

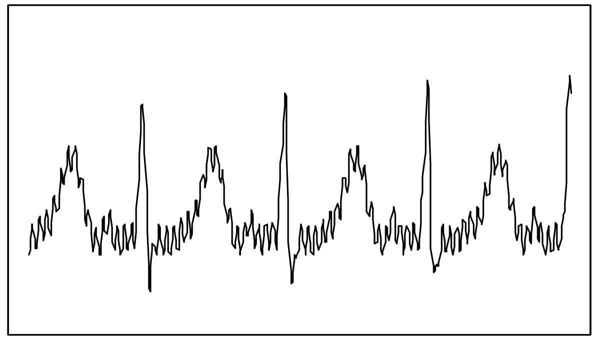


(b) IIR filtering without adaptation algorithm
$y(-1) = 0$, $y(-2) = 0$, BW =0.5 Hz

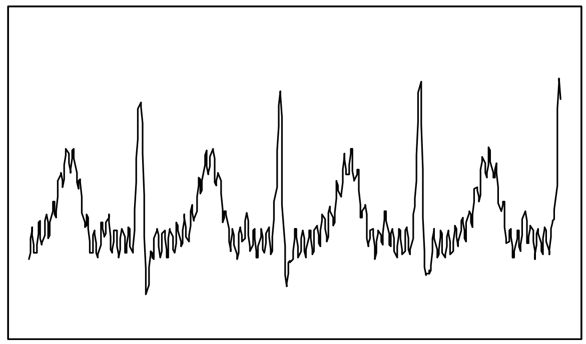


(c) Adaptive IIR Filtering
$y(-1) = 0$, $y(-2) = 0$, BW =0.5 Hz

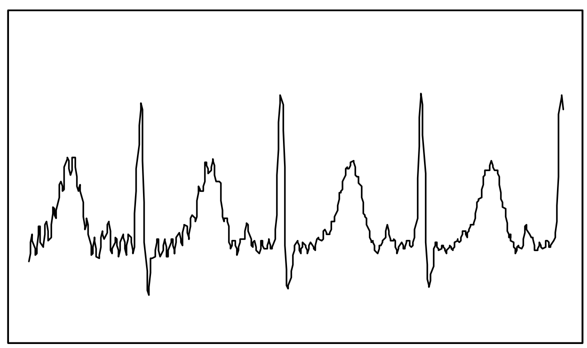
Fig. 6. Comparison of the two IIR notch filters at line frequency = 50.5 Hz. The first 400 samples are neglected and initial conditions are assumed to be zero. ($f_d = 400$, $f_s = 50$ Hz)



(a) ECG signal with 51 Hz Interference



(b) IIR filtering without adaptation algorithm
$y(-1) = 0$, $y(-2) = 0$, BW =0.5 Hz



(c) Adaptive IIR Filtering
$y(-1) = 0$, $y(-2) = 0$, BW =0.5 Hz

Fig. 7. Comparison of the two IIR notch filters at line frequency = 51 Hz. The first 400 samples are neglected and initial conditions are assumed to be zero. ($f_d = 400$, $f_s = 50$ Hz)